FLIP-CHIP LIGHT EMITTING DIODE

This application claims the benefit of provisional application serial no. 60/464,512 filed on April 22, 2003.

BACKGROUND

The present invention relates to the lighting arts. It especially relates to phosphide-based high power flip chip light emitting diodes for signaling and lighting applications, and will be described with particular reference thereto. However, the invention will also find application in conjunction with other types of flip-chip light emitting diodes and with other types of optoelectronic devices.

Light emitting diodes are increasingly being employed in outdoor displays and signal lights, indoor illumination, and other applications. High brightness AlInGaP light emitting diodes provide light in the red to amber spectral range. A mature epitaxial growth technology base exists for generating high-quality AlInGaP layers on GaAs substrates. Light emitting devices are typically fabricated by forming a mesa and depositing front and back electrodes on the topmost AlInGaP layer and on the conductive GaAs substrate, respectively. Alternatively, two front-side contacts can be employed.

Heretofore, AlInGaP light emitting diodes have not typically employed a flip-chip arrangement, such as is well-known for GaN-based ultraviolet and blue light emitting diodes. A reason for this is that unlike the transparent sapphire epitaxy substrates generally used for GaN epitaxy, GaAs substrates used in AlInGaP epitaxy are absorbing for red and amber light.

The present invention contemplates an improved apparatus and method that overcomes the above-mentioned limitations and others.

BRIEF SUMMARY

According to one aspect, a method of manufacturing a light emitting diode is provided. A plurality of semiconductor layers are deposited on a deposition substrate. At least some of the deposited semiconductor layers are removed from a selected trench region of the deposition substrate to define a light-emissive mesa. An electrode is formed on the mesa. The mesa is flip-chip bonded to a first electrical bonding pad of a thermally conductive support. The deposition substrate is removed.

According to another aspect, a flip-chip light emitting diode is disclosed. A thermally conductive support structure includes first and second electrical pads arranged on a surface of the support structure for delivering electrical power. A plurality of light-generating semiconductor layers define a light-emissive mesa electrically contacting the first electrical pad. A window layer is disposed over the light-emissive mesa and the second electrical pad. The window layer electrically contacts the second electrical pad. The window layer is light-transmissive with respect to light generated by the light-generating semiconductor layers. The window layer further is electrically conductive to define a current-spreading electrical path between the light-emissive mesa and the second electrical pad.

According to yet another aspect, a method of manufacturing a flip-chip light emitting diode is provided. Semiconductor layers that define a light emitting electrical junction are epitaxially deposited on a principle surface of an epitaxy substrate. A light-emitting device mesa is formed from the epitaxially deposited semiconductor layers. A first electrode is formed on a portion of the device mesa distal from the epitaxy substrate. The first electrode electrically contacts the device mesa. A second electrode is disposed on the principle surface

of the substrate. First and second electrodes are flip-chip bonded to bonding pads. The epitaxy substrate is removed. An electrically conductive, light-transmissive window layer is arranged over the device mesa and the second electrode. The window layer forms an electrical connection between the device mesa and the second electrode.

Numerous advantages and benefits of the present invention will become apparent to those of ordinary skill in the art upon reading and understanding the present specification.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention may take form in various components and arrangements of components, and in various process operations and arrangements of process operations. The drawings are only for purposes of illustrating preferred embodiments and are not to be construed as limiting the invention.

FIGURE **1** shows a side view of an AlInGaP light emitting diode prior to flip-chip bonding.

FIGURE **2** shows a side view of the AlInGaP light emitting diode epitaxial structure of FIGURE **1** flip-chip bonded to a support, with the epitaxy substrate removed.

FIGURE **3A** shows a top view of the p-type and n-type electrodes of the AlInGaP light emitting diode epitaxial structure of FIGURE **1**.

FIGURE **3B** shows a top view of alternative p-type and n-type electrodes with a larger p-type electrode-to-n-type electrode area ratio.

FIGURE **4** shows a side view of another AlInGaP light emitting diode epitaxial structure, flip-chip bonded to a support.

FIGURE **5** shows a side view of the flip-chip bonded AlInGaP light emitting diode epitaxial structure of FIGURE **4**, with the epitaxy substrate removed and a window layer deposited.

It is to be appreciated that the FIGURES are for exemplary purposes only and are not drawn to scale.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

With reference to FIGURE **1**, an AlInGaP light emitting diode epitaxial structure **10** includes a GaAs epitaxy substrate **12**, a window layer **14** epitaxially deposited on the GaAs substrate **12**, and a plurality of light-emitting semiconductor layers **16**, **18**, **20** epitaxially deposited on the window layer **14**. In the exemplary illustrated device structure **10**, the light-emitting semiconductor layers **16**, **18**, **20** include an n-type AlInGaP layer **16** and a p-type AlInGaP layer **20**, with an active region **18** of low-doped (typically not intentionally doped) AlInGaP disposed therebetween. In a preferred embodiment, the semiconductor layers **16**, **18**, **20** are epitaxially deposited using metalorganic chemical vapor deposition (also known as organometallic vapor phase epitaxy or the like). In another suitable embodiment, molecular beam epitaxy is used to deposit semiconductor layers **16**, **18**, **20**.

In operation, holes and electrons are supplied to the active region **18** that is arranged at the electrical junction of the p-type and n-type layers **16**, **20**. Electron-hole pairs radiatively recombine in the active region **18** to emit light. The spectral distribution of emitted light is generally determined by characteristics of the active region **18**, such as the composition and bandgap of the AlInGaP layer **18**.

The illustrated light-emitting semiconductor layers **16**, **18**, **20** are exemplary only. Those skilled in the art can readily include other or additional semiconductor layers for achieving specific light emission characteristics. For example, the active region can include quantum wells. Additional heavily doped p- and/or n-type layers can be incorporated to improving electrical current injection into the active region **18**. The alloy compositions of the AlInGaP layers are selected to obtain desired bandgap, optical, and other material characteristics

while remaining substantially lattice-matched to GaAs. However, as is known in the art some lattice mismatch can be included, especially in thinner layers such as active region quantum wells, to produce coherently strained layers. Incorporation of one or more strain-relaxed lattice-mismatched layers is also contemplated. However, in view of material degradation that typically occurs due to defects introduced by strain relaxation, lattice-matched or coherently strained layers are generally preferred.

The window layer **14** is selected to be substantially electrically conductive and light-transmissive for light generated by the light-emitting semiconductor layers **16**, **18**, **20**. Unless the semiconductor layers **16**, **18**, **20** are intended to be strain-relaxed, the window layer **14** should also be lattice-matched to the GaAs substrate. For the exemplary AlInGaP light emitting diode structure, suitable materials for the window layer **14** include ternary AlGaAs, which is lattice-matched to GaAs for most compositions, and wide-bandgap AlInGaP materials such as AlInP. To provide adequate light extraction and electrical current spreading, the window layer **14** preferably has a thickness of at least two microns.

A device mesa **24** is defined by selectively removing the semiconductor layers **16**, **18**, **20** in selected trench regions **26** of the substrate **12**. In a preferred embodiment, the trench regions **26** are formed photolithographically. A p-type electrode **30** is formed on a surface of the device mesa **24** distal from the substrate **12**. An n-type electrode **32** is disposed on the substrate **12** by forming the electrode **32** on the window layer **14** in the trench region **26**. Optionally, an insulating layer **34** is deposited between the device mesa **24** and the n-type electrode **32** to ensure substantial electrical isolation therebetween. The electrodes **30**, **32** and optional insulator **34** are suitably formed by evaporation, sputtering, or otherwise depositing the metal or insulator material, in conjunction with photolithographic processing. The electrodes **30**, **32** can be formed of the same or different material. Typically, each electrode includes a metal layer stack designed to provide an approximately ohmic contact with the semiconductor **20** or the window layer **14**.

Those skilled in the art recognize that the AlInGaP light emitting diode epitaxial structure **10** is similar to a conventional AlInGaP light emitting diode epitaxial structure, except that the window layer **14** is arranged adjacent to the epitaxy substrate **12**. In contrast, in a conventional AlInGaP light emitting diode epitaxial structure the window layer, if present, is arranged as a topmost layer or a nearly topmost layer of the epitaxial semiconductor layer stack. That is, in a conventional AlInGaP light emitting diode epitaxial structure, the window is arranged in the semiconductor stack distal from the substrate, rather than adjacent thereto.

With reference to FIGURE **2**, the AlInGaP light emitting diode epitaxial structure **10** is flip-chip bonded to p-type and n-type electrical bonding pads **40**, **42** of a thermally conductive sub-mount **44** via solder bumps **46**, **48** respectively. After flip-chip bonding, the GaAs substrate **12** is removed by chemical etching, plasma etching, or another suitable technique to expose the window layer **14**. Preferably, the window layer **14** acts as an etch stop. For example, certain phosphoric acid/hydrogen peroxide aqueous solutions are known to be highly selective for etching GaAs over phosphide-based semiconductors. Rather than or in conjunction with chemical or plasma etching, mechanical polishing can be used to remove or thin the epitaxy substrate **12**.

After substrate removal, the exposed surface **50** of the window layer **14** is optionally roughened, patterned, or otherwise modified to further improve light extraction. Light extraction can be improved by forming a Fresnel lensing pattern on the surface **50**, or by applying an epoxy coating, plastic coating, refractive index matching coating after removal of the epitaxy substrate **12**. A micro-lens can also be bonded to the exposed surface **50**. Optionally, the device mesa **24** can additionally include a distributed Bragg reflector or other reflective layer or layers (not shown) disposed between the p-type AlInGaP layer **20** and the p-type electrode **30** during epitaxy to further increase reflectivity.

In operation, electrical bias applied at the electrical bonding pads **40**, **42** energize the device through a current path (traced in the following from positive

to negative) including: the p-type bonding pad **40**; the solder bump **46**; the p-type electrode **30**; the device mesa **24**; the current-spreading window layer **14**; the n-type electrode **32**; the solder bump **48**; and the n-type bonding pad **42**. Light emitted by the device mesa **24** passes out the window layer **14** via the surface **50** as the device light output. Light generally directed toward the p-type electrode **30** is reflected toward the window layer **14** and also contributes to the device light output through the surface **50**.

To enable chip-scale package design, bonding pads **40**, **42** for a plurality of light emitting diodes can be interconnected by printed circuitry on the sub-mount **44** or other support structure. Moreover, the support structure can include driving electronics connected to the light emitting diodes by the printed circuitry.

With reference to FIGURE **3A**, the electrodes **30**, **32** are arranged with a gap **52** therebetween. However, other electrode configurations can also be employed, such as the configuration shown in FIGURE **3B**, in which a p-type electrode **54** is made larger compared with the electrode **30**, while an n-type electrode **56** is made smaller. A large p-type electrode-to-n-type electrode area ratio is advantageous since the light emitting mesa underlies the p-type electrode. (However, it will be recognized that if the polarity of the mesa is reversed, so that the n-type electrode is on the mesa, then a large n-type electrode-to-p-type electrode area ratio is advantageous). The optimal electrode area ratio depends upon various factors including chip size, current spreading capability of the window layer, and the ohmic contact quality of the electrodes.

With reference to FIGURE **4**, another AlInGaP light emitting diode epitaxial structure **10'** includes a GaAs epitaxy substrate **12'** and a plurality of light-emitting semiconductor layers **16'**, **18'**, **20'** epitaxially deposited on the GaAs epitaxy substrate **12'**. A device mesa **24'** is defined by selectively removing the semiconductor layers **16'**, **18'**, **20'** in selected trench regions **26'** of the substrate **12'**. A p-type electrode **30'** is formed on a surface of the device mesa **24'** distal from the substrate **12'**. An n-type electrode **32'** is disposed on the substrate **12'** by

forming the electrode **32'** on the epitaxy substrate **12'** in the trench region **26'**. Optionally, an insulating layer **34'** is deposited between the device mesa **24'** and the n-type electrode **32'** to ensure substantial electrical isolation therebetween.

It will be recognized that the epitaxial structure **10'** is generally similar to the epitaxial structure **10** of FIGURE **1**, except that the epitaxially grown window layer **14** of the epitaxial structure **10** is omitted. The epitaxial structure **10'** is flip-chip bonded to p-type and n-type electrical bonding pads **40'**, **42'** of a thermally conductive sub-mount **44'** via solder bumps **46'**, **48'** respectively.

With reference to FIGURE **5**, after flip-chip bonding, the GaAs substrate **12'** is removed by chemical etching, plasma etching, or another suitable technique. Removal of the epitaxy substrate **12'** exposes the n-type AlInGaP layer **16'** and a surface of the n-type electrode **32'** where it had contacted the substrate **12'**. Removal of the GaAs substrate **12'** effects a physical separation of the mesas **24'** at the trenches **26'**. After removal of the epitaxy substrate **12'**, a substantially electrically conductive and light-transmissive window layer **14'** is deposited over the n-type AlInGaP layer **16'** and the exposed surface of the n-type electrode **32'** to form an electrically conductive connection therebetween.

Because the window layer **14'** is deposited after epitaxial growth of the semiconductor layers **16'**, **18'**, **20'**, the window layer **14'** is generally not epitaxial with respect to the semiconductor layers **16'**, **18'**, **20'**. Rather, the window layer **14'** can be selected for preferred electrical and optical characteristics. Suitable materials for the window layer **14'** include sputtered indium tin oxide, GaP or AlGaAs grown by liquid phase epitaxy, or the like. The window layer **14'** is preferably at least two microns thick; hence, a fast deposition technique such as sputtering or liquid phase epitaxy is preferably employed. In contrast, the epitaxial window **14** of the embodiment of FIGURES **1** and **2** is grown along with semiconductor layers **16**, **18**, **20** by metalorganic chemical vapor deposition or molecular beam epitaxy, which are slower layer deposition techniques.

The electrodes **30'**, **32'** are typically metal layer stacks optimized to provide approximately ohmic contact with the p-AlInGaP layer **20'** and the window

layer **14'**, respectively. Moreover, if the electrical characteristics of a direct junction between material of the window layer **14'** and material of the solder bump **48'** are sufficiently ohmic, the n-type electrode **32'** is optionally omitted.

A surface **50'** of the window layer **14'** is optionally roughened or patterned (for example with a Fresnel lens pattern) to further improve light extraction. Additionally, an encapsulant **60** can be included adjacent to the surface **50'** and surrounding the light emitting diode device to hermetically seal the light emitting diode and to improve light extraction. Similarly, a microlens or other light-coupling element can be bonded to the surface **50'** of the window layer **14'**.

Although AlInGaP light emitting diodes have been illustrated, those skilled in the art can readily adapt these exemplary devices to the manufacture flip-chip bonded light emitting diodes in other materials systems that are grown on epitaxy substrates that substantially absorb the light output.

The invention has been described with reference to the preferred embodiments. Obviously, modifications and alterations will occur to others upon reading and understanding the preceding detailed description. It is intended that the invention be construed as including all such modifications and alterations insofar as they come within the scope of the appended claims or the equivalents thereof.